

USAGE OF NASA'S NEAR REAL-TIME SOLAR AND METEOROLOGICAL DATA FOR MONITORING BUILDING ENERGY SYSTEMS USING RETSCREEN INTERNATIONAL'S PERFORMANCE ANALYSIS MODULE

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ABSTRACT

This paper describes building energy system production and usage monitoring using examples from the new RETScreen Performance Analysis Module, called *RETScreen Plus*. The module uses daily meteorological (i.e., temperature, humidity, wind and solar, etc.) over a period of time to derive a building system function that is used to monitor building performance. The new module can also be used to target building systems with enhanced technologies. If daily ambient meteorological and solar information are not available, these are obtained over the internet from NASA's near-term data products that provide global meteorological and solar information within 3-6 days of real-time. The accuracy of the NASA data are shown to be excellent for this purpose enabling RETScreen Plus to easily detect changes in the system function and efficiency. This is shown by several examples, one of which is a new building at the NASA Langley Research Center that uses solar panels to provide electrical energy for building energy and excess energy for other uses. The system shows steady performance within the uncertainties of the input data. The other example involves assessing the reduction in energy usage by an apartment building in Sweden before and after an energy efficiency upgrade. In this case, savings up to 16% are shown.

1. INTRODUCTION

The monitoring, targeting and verification of a building's energy usage depends upon many factors. One of the most important of which is the ambient conditions to which it's electrical, heating and air conditioning systems must respond. Incorporating renewable energy systems, including solar systems, to supplement energy supplies and increase energy efficiency is important to saving costs and reducing emissions. Retrofitting technologies to buildings requires knowledge of building performance in its current state, projection of potential savings with capital investment, and then monitoring the performance once the improvements are made.

RETScreen International[1] is a division of Natural Resources Canada (NRCan), dedicated to developing and providing clean energy software for the feasibility assessment of a wide range of building projects that incorporate renewable-energy and energy-efficient technologies (RETs). RETScreen has recently developed a new Performance Analysis Module entitled RETScreen Plus that is a Windows-based energy management software tool that allows project owners to easily verify the ongoing energy performance of their facilities. RETScreen Plus uses daily average data that is delayed less than a month of real-time (although longer time averages can be supported).

This data can be provided by direct measurements at the building location. However, frequently such observation data is missing or incomplete and so RETScreen has collaborated with NASA to provide estimates of the needed data quantities for any location in the world. The NASA CERES (Clouds and Earth's Radiance Energy System)/FLASHFlux (Fast Longwave and SHortwave radiative Fluxes)[2] data set provides solar fluxes and the NASA GMAO (Global Modeling and Assimilation Office) GEOS (Goddard Earth Observing System) [3] operational meteorological analysis provides meteorological parameters within 3-6 days of real-time. These respective outputs are specially tailored to provide inputs to the new RETScreen Plus.

This paper provides a demonstration of the utility of RETScreen Plus and the near real time NASA solar and meteorological parameters to assess a building's energy performance over multi-year time scales. First, the parameters required by RETScreen Plus and supplied from the NASA data sets are described, then two examples of using the tools to identify performance issues are discussed. The first example analyzes the electrical production of a solar panel system retrofitted to a building at NASA Langley Research Center showing consistent performance, within the accuracies of the input data sets. The second example shows the change and savings in an apartment building after an energy efficient upgrade. Both these examples use RETScreen Plus coupled with input data adapted from NASA data products.

2. RETSCREEN PERFORMANCE ANALYSIS

RETScreen International, as supported by Natural Resources Canada, has developed a comprehensive Clean Energy Project Analysis Software to provide decision makers pre-feasibility information regarding a wide range of renewable energy, cogeneration and energy efficiency projects. The software package has more than 330,000 registrants from all over the world and is provided in 36 languages. Recently, RETScreen has added a Performance Analysis Module to enable "users to monitor, analyze and report key energy performance data to facility operators, managers and senior decision-makers"[1]. This tool was developed in collaboration with the Renewable Energy and Energy Efficiency Partnership (REEEP) and the NASA Langley Research Center in support of the growing need for energy monitoring, targeting and reporting (MT&R) to "better manage energy project investments as well as identify additional project opportunities"[4]. The general procedure for RETScreen Plus is illustrated by the MT&R feedback loop shown in Fig 1. With energy

MT&R FEEDBACK LOOP

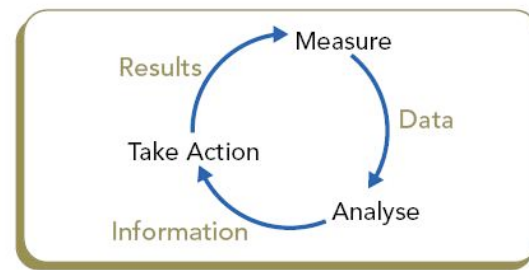


Fig 1: A depiction of the Monitoring, Targeting and Reporting (MT&R) feedback loop capture in the new RETScreen Performance Analysis Module.

usage data (measure) coupled with meteorological and solar information (ancillary data) as inputs the performance module (analyze) provides the ability to understand a particular building's energy needs and quantify improvements relative to its usage and environment.

3. NASA'S NEAR-TERM GLOBAL DATA SETS

As noted above and depicted in Fig. 1, an important part of MT&R is the provision of environmental data in which a particular building is located. The NASA Langley Research Center has developed a near-term data product stream at a global $1^\circ \times 1^\circ$ spatial resolution providing estimates of basic meteorological information within 1 week of real-time. The data products are being produced and made available on the internet by NASA's Prediction Of Worldwide renewable Energy Resource project (POWER) [5,6]. Table 1 identifies the parameters available in the data stream, their sources and their availability. Estimates of basic meteorological quantities are obtained from the GMAO GEOS 5.2 atmospheric reanalysis and remapped to $1^\circ \times 1^\circ$. Atmospheric reanalysis data products are essentially an output of an atmospheric general circulation model with initial conditions and forecasts optimized using surface (i.e., weather stations, ships, etc.), in air (i.e., radiosonde, aircraft, etc.), and satellite measurements. These data products are available within 3-4 days of the model run. The atmospheric temperature and humidity profiles produced by GEOS-5 also are infused into the data production of the CERES FLASHFlux project which is providing the estimates of the global solar and thermal infrared energy fluxes at the surface of the Earth [2]. Precipitation information is available from GEOS-5, however daily precipitation estimates from the Global Precipitation Climatology Project (GPCP) appear to agree better relative to individual range gage data, but are delayed and are currently a couple years behind real-time and should be used in a climatological sense [7]. More detailed discussion about the accuracy of these data is found in "Sustainable Buildings" methodology

TABLE 1: Parameters provided through the NASA near-term data stream to RETScreen Plus. A description of each parameter, its source, availability and the status of current use by RETScreen is shown.

Parameter name	Parameter description	Primary Unit	NASA Data Source	Availability? (days)	Used by RETScreen?
swv_dwn	Average Insolation Incident On A Flat Surface	kWh/m ² /day	FLASHFlux	5-6	Yes
lwv_dwn	Average Downward Longwave Radiative Flux	kWh/m ² /day	FLASHFlux	5-6	No
toa_dwn	Average Top-of-atmosphere Insolation	kWh/m ² /day	FLASHFlux	5-6	No
avg_kt	Average Insolation Clearness Index	0 to 1.0	FLASHFlux	5-6	No
clr_sky	Average Clear Sky Insolation On A Flat Surface	kWh/m ² /day	FLASHFlux	5-6	No
clr_kt	Average Clear Sky Insolation Clearness Index	0 to 1.0	FLASHFlux	5-6	No
PS	Average Atmospheric Pressure	kPa	GEOS-5	3-4	Yes
T2M	Average Air Temperature At 2 m	degrees C	GEOS-5	3-4	Yes
T2MN	Minimum Air Temperature At 2 m	degrees C	GEOS-5	3-4	Yes
T2MX	Maximum Air Temperature At 2 m	degrees C	GEOS-5	3-4	Yes
Q2M	Average Humidity Ratio At 2 m	%	GEOS-5	3-4	No
RH2M	Relative Humidity At 2 m	%	GEOS-5	3-4	Yes
DFP2M	Dew/Frost Point Temperature At 2 m	degrees C	GEOS-5	3-4	No
RAIN	Average Precipitation	mm/day	GPCP	Months	No
TSKIN	Average Earth Skin Temperature	degrees C	GEOS-5	3-4	Yes
WS10M	Wind Speed At 10 m	m/s	GEOS-5	3-4	Yes

document found on the web site [8]. Finally, Table 1 also shows which data parameters are used in RETScreen Plus.

4. EXAMPLES OF PERFORMANCE ANALYSIS USAGE

In this section, the application of RETScreen Plus in conjunction with the NASA derived data is illustrated for a sample of building system energy production and usage during the last 1-3 years. The examples illustrate both the results obtainable using the tool and also its use of solar irradiance and temperature data from the NASA data sets.

4.1 Solar Energy Production at the NASA Langley Research Center Badge and Pass Office

The NASA Langley Research Center recently completed construction to retrofit a 39.5 KW ground mounted solar power system to an existing Badge and Pass security office building. The system is designed to produce around 50,000 KW-hr of energy each year using a tilt of 20° and a due south orientation. The output of this system can be modeled using the Performance Analysis Module to evaluate the system performance relative to its design characteristics.

To begin, the assessment the daily electrical output from the solar panel is obtained from the NASA facility. Since no solar measurement data is available at the site, the estimated daily solar irradiance is downloaded using a link to the NASA POWER web site built within the tool. In this case, since the solar panel system was added to the building in September 2010, the data from October 2010 through February 2012 are downloaded. Using these data a sample analysis of the system is performed using RETScreen Plus on a daily basis. First, solar panel electrical output is compared directly to tilted solar irradiance estimates and the result of this is shown for a 4-month period in the top panel of Figure 2. This panel shows that the NASA's solar irradiance variability corrected to the proper tilt with RETScreen Plus, correlates very well with the variability of the electrical output of the systems.

Given the excellent agreement, RETScreen Plus provides an analysis of system electrical output as a function of the parameters shown in Table 1. During this analysis period it was discovered that the system documentation tilt did not properly correspond to the solar irradiance variation over the whole solar cycle. It was inferred that a larger slope was

needed. After re-measurement it was determined that the system actual tilt was about 26° . Thus, RETScreen Plus with the NASA data was able to detect a problem in the system specification. After these adjustments, it was determined that the best fit to the meteorological data was a multi-variant fit using the tilted solar irradiances, temperature and surface pressure. The resulting curve fit is shown in the middle panel of Figure 2. This fit produces an R^2 of 0.88. Note that the solar panel system provides no electrical output for tilted solar irradiance less than about 1 kWh/m²/day.

RETScreen Plus then provides a control plot (not shown) that gives the difference between the electrical output of each day compared to the various daily solar and meteorological inputs needed for the function. In this instance, most days gave agreement within about 5% of the system function fit but some outliers were as large as $\pm 50\%$. The variations were explored using nearby weather station of precipitation, etc. but the variations did not correlate with precipitation events nor even a period occasionally containing smoke aerosols from a fire 100 km to the southwest. NASA's surface horizontal irradiance was compared with measurements from surface sites 20 km and 100 km away and these showed excellent correlation between the surface measurements and the NASA satellite based estimates (not shown). Another potential source of day-to-day variability lies in system abnormalities but there were not day-to-day logs of such information to consult.

The last step of the RETScreen Plus analysis uses the accumulated sums of the daily differences between the system function and the observed electrical output to assess the overall system performance. This parameter called the CUSUM provides an excellent way to observe the system performance over time and identify potential changes to the system. The bottom panel of Figure 2 shows the CUSUM from the time of installation through Feb. 2012. Changes of slope of this curve are indicative of the accumulated excess or deficit electrical energy produced by the system relative to the system function. So, the system appears to have produced electricity according to the original function but with some amount of variability. The system produced about 59,000 KWh in its first year, so the observed variability of ± 300 kWh represents only about 0.5% of that total. The amount of energy produced by the system in its first year exceeded the system documentation by 18%. This is probably explained in part by the error in the tilt angle (at this location the higher tilt angle of 26° is more effective than 20°) and by the fact that the solar irradiance for 2011 was found to be approximately 5% higher than normal. This example shows how RETScreen Plus coupled with the NASA data is useful for diagnosing and monitoring the solar panel system performance.

4.2 Apartment Building in Sweden

Another example of the RETScreen Performance Analysis Module used in conjunction with the NASA POWER data stream is shown in Figures 3 and 4. In this example, the energy usage of an apartment building in Sweden is assessed using heating degree day information derived from the NASA temperature data and using reference standard of 16°C (note RETScreen Plus allows one to customize the heating/cooling degree day reference temperatures). This building uses about 1,600 MWh of energy annually. There are nearly 4 years of data analyzed in this example in two different ways.

At first, the building energy usage information was compared to heating degree-day temperatures over the entire period as shown in the top panel of Figure 3. The green line represents the building energy consumption as a linear function of the heating degree-days. The monthly cumulative sum difference plot between actual and predicted energy usage shows that there is a distinct period where energy usage exceeds the function and one where the opposite is true (Figure 3, bottom panel). In this case, the apartment buildings were improved with an energy efficiency upgrade of control systems at times as labeled. Thus, the CUSUM difference plot identifies clearly when the building upgrades were completed.

Given the building system change, the RETScreen analysis was then performed for the period leading up to the upgrade to derive the previous building energy consumption function. This new fit is shown in the top panel of Figure 4. The R^2 value of this fit was 0.9952. The bottom panel of Figure 4 shows the new CUSUM difference plot. Now, the initial period is shown to exhibit excellent agreement with the system function. However, after the changes the buildings consistently use less energy. The amount of energy saved is easily computed relative to the pre-upgrade system function of the buildings and amounts to 224 MWh in year 1 and 337 MWh in year 2 as labeled. In Sweden, the cost of energy is roughly \$100/MWh so the energy savings exceeded \$50,000 US after the two years after the upgrade and amounted to a 16% savings in energy costs.

5. SUMMARY AND CONCLUSIONS

This paper shows the power of the new *RETScreen Plus* Performance Analysis Module to identify and assess changes to building energy system performance accounting for the variability of weather. This new Monitoring, Targeting & Reporting (MT&R) tool models building energy systems as a function of their environmental conditions. This model is then used to evaluate the system performance and can be used to identify unexpected changes in energy production or usage. The key to a

successful application of is the availability of a consistent set of accurate historical and current environmental data. The NASA Langley Research Center has developed an automated database of satellite-derived daily values of surface meteorological parameters for a 25+ year period and in near real-time, for the entire surface of the planet. Parameters include, for example, daily temperature from July 1983 to present with a maximum delay of one week relative to real-time. The RETScreen user is able to automatically download historical and near real-time data from NASA's web servers and directly upload it into this data section of the Performance Analysis Module. This makes weather-related data collection a simple task for projects anywhere in the world.

This paper presented the results and discussed the application of RETScreen Plus to two difference building systems: a) the production of energy from a solar power system located in Hampton, VA, USA and b) the usage of energy in an apartment building located in Sweden. A multi-variant function using estimates of solar irradiance, temperature and surface pressure was used to assess the performance of the solar panel system. The analysis was sensitive enough to infer an initial problem in the specification of the system tilt. Upon correction, the system was found to perform even beyond the initial quoted target due both the actually system tilt and due to an excess of solar energy received at the site in 2011. In the second example, the energy usage was modeled using a system function depending upon heating degree analysis and was used to infer correctly the times of a system upgrade and verify the system upgrade improved performance relative to variation in the weather providing enough information to estimate the cost savings (i.e., payback of the upgrade).

The application of RETScreen Plus shows its diversity and usefulness to different types of building systems. The utility of the NASA data is shown to enable the application of the tool to diverse locations in the world. By coupling these together, MT&R analysis of building systems is possible for any location on the globe.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

- (1) RETScreen International web page:
<http://www.retscreen.net>.
- (2) Stackhouse Jr., P.W., D.P. Kratz, G.R. McGarragh, S.K. Gupta and E.B. Geier, Fast Longwave and Shortwave Radiative Flux (FLASHFlux) Products from CERES and

MODIS Measurements. Proceedings of the 12th Conference on Atmospheric Radiation. American Meteorological Society. Madison, WI, July 10-14, 2006.

- (3) Rienecker, M.M, M.J. Suarez, R. Todling, J. Bacmeister, L. Takacs, H.-C. Liu, W. Gu, M. Sienkiewicz, R.D. Koster, R. Gelaro, I. Stajner, and E. Nielsen, 2007: The GEOS-5 Data Assimilation System - Documentation of Versions 5.0.1, 5.1.0, and 5.2.0, NASA Technical Report Series on Global Modeling and Data Assimilation, Max J. Suarez, Editor, NASA/TM-2007-104606, Vol. 27

- (4) The Performance Analysis web address is:
http://www.retscreen.net/ang/performance_analysis.php, last modified 2012-01-27.

- (5) NASA Prediction of Worldwide renewable Energy Resource (POWER) web site: <http://power.larc.nasa.gov>.

- (6) Chandler, William S., P.W. Stackhouse, Jr., C.H. Whitlock, J.M. Hoell, D. Westberg, T. Zhang, 2010: Near Real-time Global Radiation and Meteorology Web Services Available from NASA. Proceedings of the Solar 2010 Conference (American Solar Energy Society), May 18-22, Phoenix, Arizona

- (7) Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin, E. Nelkin 2003: The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present). J. Hydrometeor., 4, 1147-1167.

- (8) Prediction Of Worldwide Energy Resource (POWER): Sustainable Buildings Methodology, Version 1.0, March 1, 2012. Web site address:

http://power.larc.nasa.gov/common/BuildingMethodology/Building1d0_Methodology_Parm-n-Sources.html

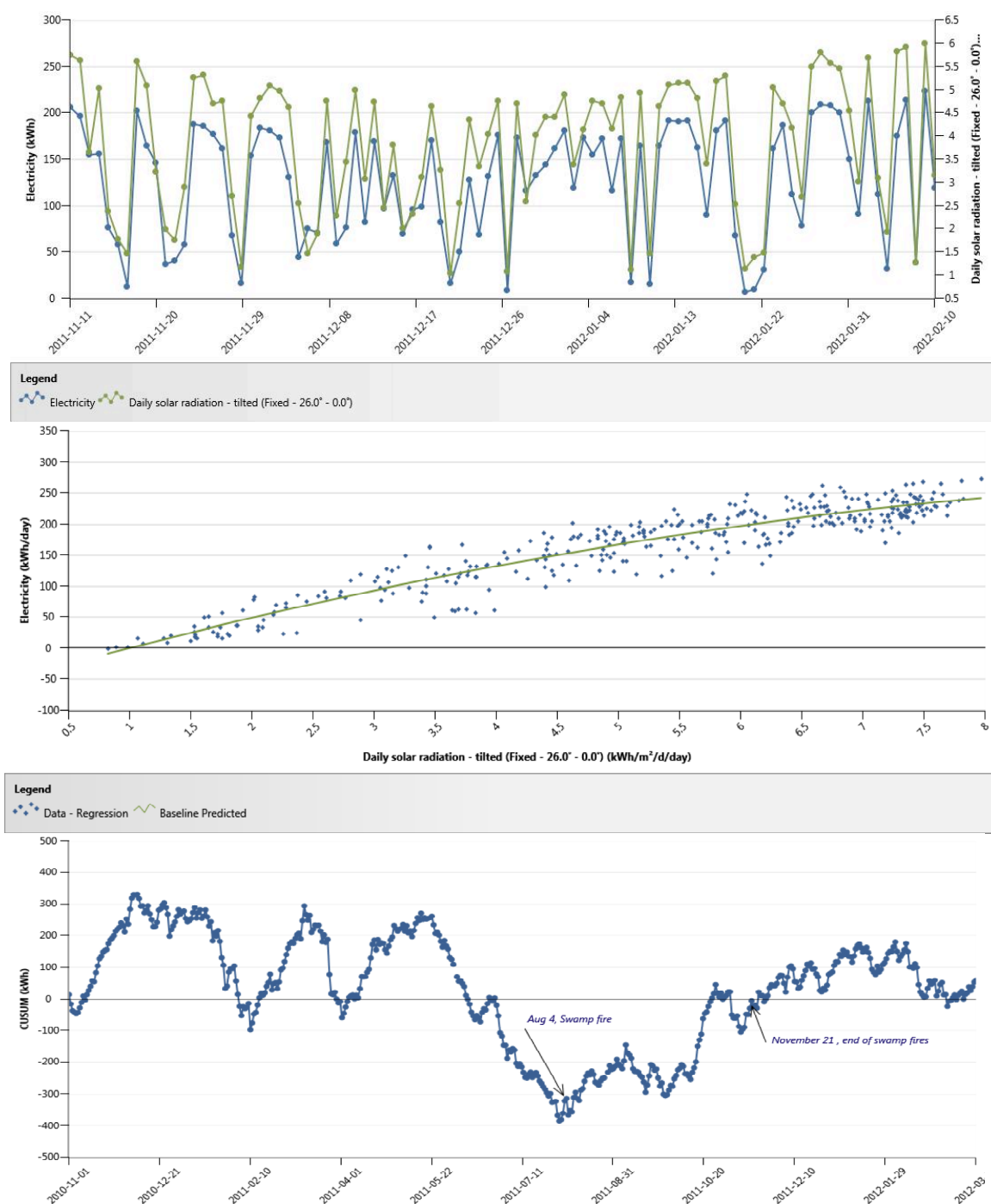


Fig. 2: A sample analysis of the electrical output of the 39.5 kW solar panel system attached to the NASA Langley Research Center Badge and Pass Office building. Top panel shows the correspondence of the daily average electrical output of the array to the daily average solar irradiance estimated from satellite and adjusted to a tilted surface. The middle panel shows the result of a multi-variant system fit of solar irradiance, temperature and surface pressure through the electrical output data. The bottom panel shows the cumulative difference between the performance of the system and the predicted system function (CUSUM) that is used to study system performance over time.

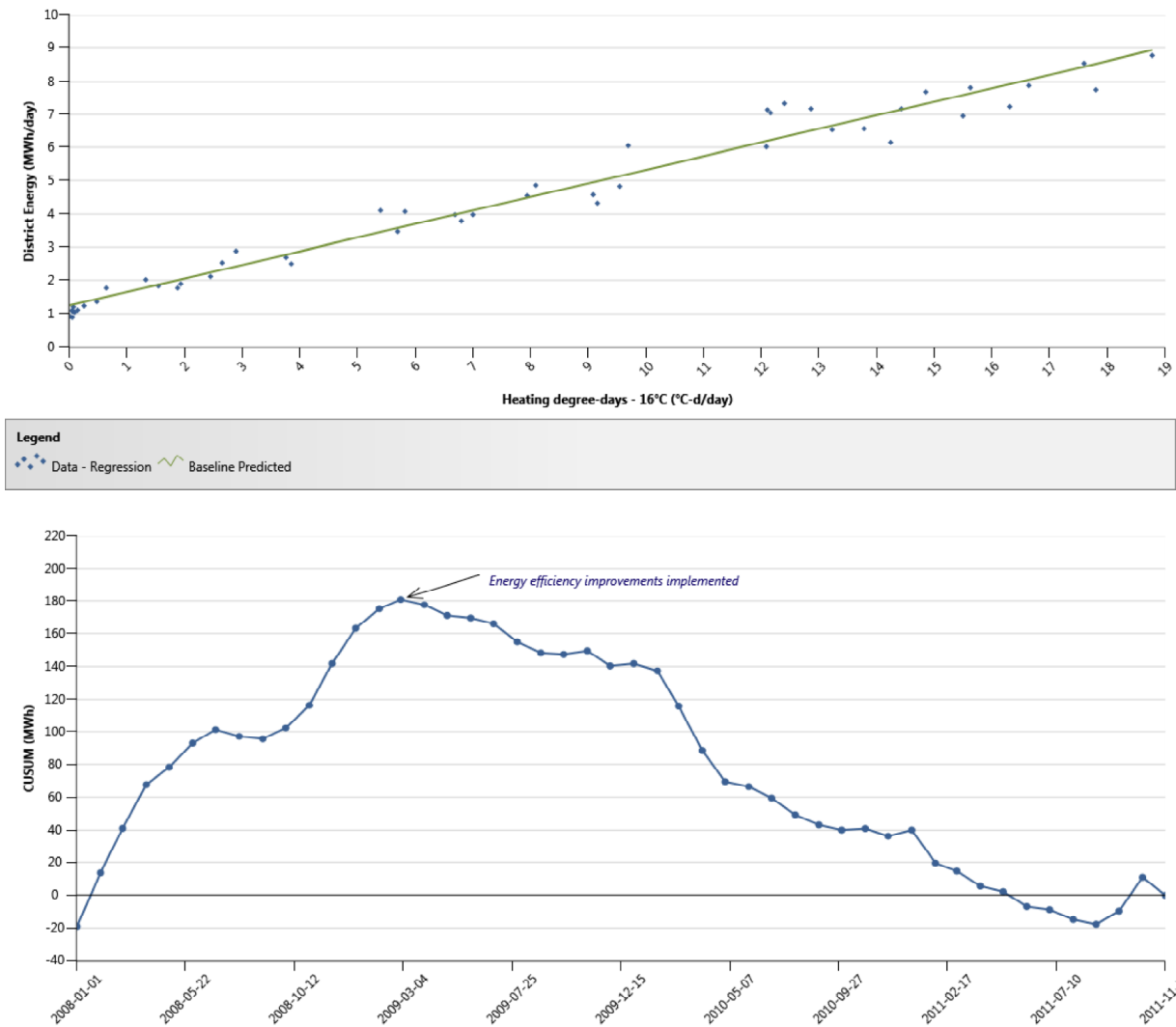


Fig. 3: Initial analysis of an apartment building in Sweden that uses about 1,600 MWh of energy. The top panel shows the relationship between heating degree days and the building energy usage for nearly a 4 year period using NASA surface temperatures and a reference temperature of 16°C to compute the Heating degree day. The bottom panel shows the cumulative difference between the performance of the system and the predicted system function. Note that an energy efficiency upgrade was made to the building in March 2009 that resulted in a systematic decrease in energy usage thereafter.

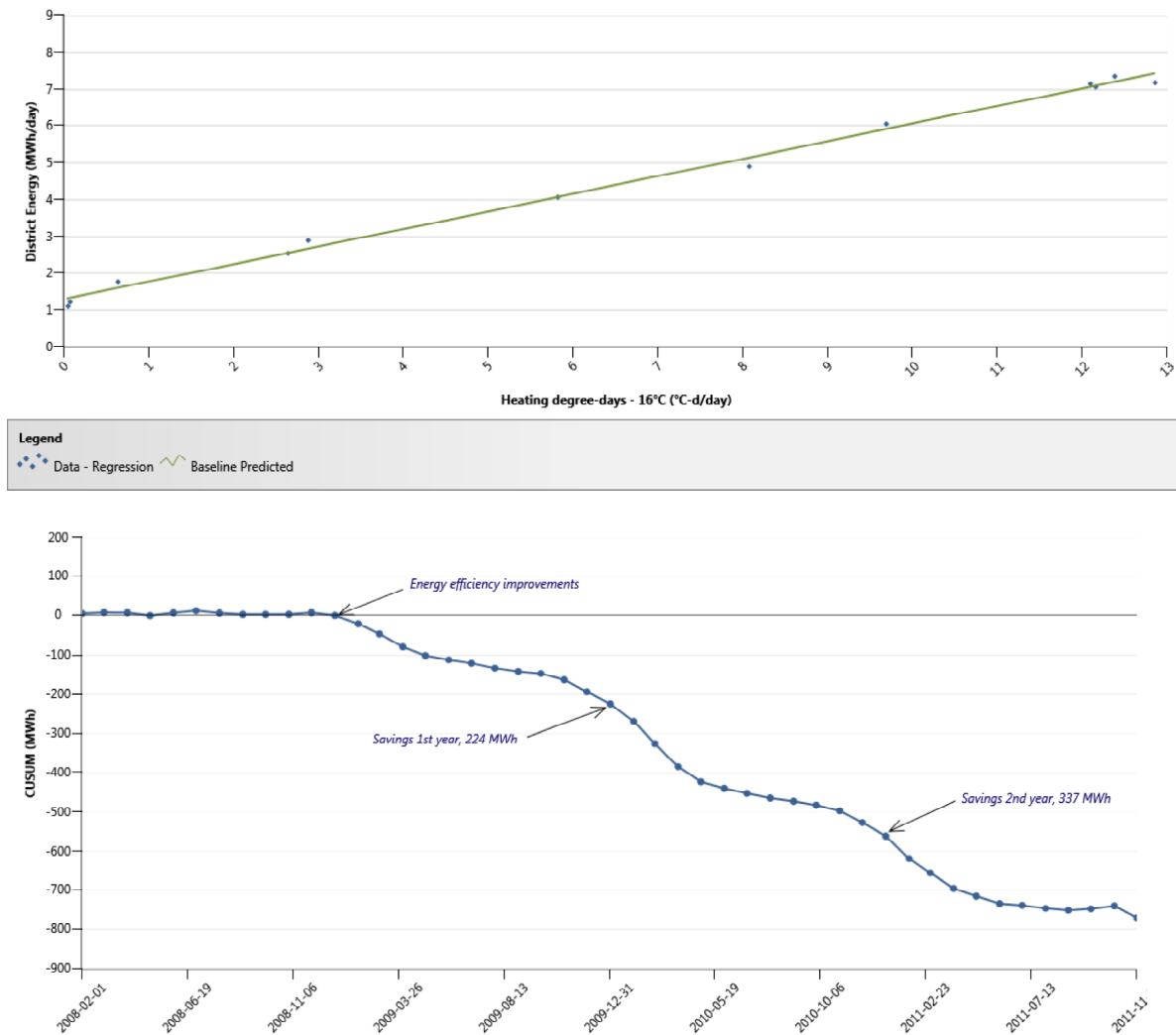


Fig. 4: Revised analysis of the apartment building in Sweden analyzed in Fig. 3. The top panel shows the relationship between heating degree-days and the building energy usage for the period leading up to the energy efficiency upgrade to the building. The bottom panel shows the cumulative difference between the performance of the system and the revised predicted system function (shown by the green line in the top panel). The revised analysis clearly shows the month-to-month reduction in energy usage with the total amount of energy saved noted. In Sweden, the price for electricity is roughly \$100 MWh so; this upgrade represented a 2 year savings of over \$50,000 US.